42-Story Dewitt-Chestnut Apartments Re-imagined: The SOM Timber Tower Research Project

Presented on November 6th, 2014 by Benton Johnson

Disclaimer: This presentation was developed by a third party and is not funded by WoodWorks or the Softwood Lumber Board.
42-Story Dewitt-Chestnut Apartments Re-imagined: The SOM Timber Tower Research Project

National Symposium: Toward Taller Wood Buildings
November 6th, 2014

Benton Johnson, PE SE
Skidmore, Owings & Merrill, LLP
benton.johnson@som.com
Timber Research to Date

Initial Report:
Released May 2013

System Report #1:
Released May 2014

Project Specific:
Ongoing
SOM Research
SOM Legacy Research

THE TALL BUILDING: THE EFFECTS OF SCALE
Myron Goldsmith, Masters in Architecture, 1953; Illinois Institute of Technology (IIT)

Advisor: Mies van der Rohe
SOM Legacy Research

**THE TALL BUILDING: THE EFFECTS OF SCALE**
Myron Goldsmith, Masters in Architecture, 1953; Illinois Institute of Technology (IIT)

Advisor: Mies van der Rohe
SOM Legacy Research

**A TALL OFFICE BUILDING**
Mikio Sasaki, Master of Science in Architecture, 1964; Illinois Institute of Technology (IIT)

Advisor: Myron Goldsmith
Structural Advisor: Fazlur Khan
SOM Legacy Research

John Hancock Center
Chicago, IL (1970)
SOM Legacy Research

CTBUH Proceedings, 1974
SOM Contemporary Research

Tower Palace III
Seoul, South Korea (2004)

Burj Khalifa
Dubai, UAE (2010)
SOM Contemporary Research

Cantilevered Core / Super Core
R&D Award Winner, Architect Magazine (2011)
SOM Ongoing Research

Metropolis Magazine, March 2014
Research Motivation

\[
\text{Steel Quantity [psf]} \approx 0.019(\text{Height in Ft}) + 12.0
\]
Research Motivation

- Structural Steel Quantity vs. Height
- Steel Quantity [psf] ≈ 0.019(Height in Ft) + 12.0
- Steel Embodied CO2e [psf] ≈ 0.034(Height in Ft) + 21.6
Basis of Timber Research
Basis of Research

2013: 7.0 billion Total -- 3.5 billion in Cities

2050: 11.0 billion Total -- 7.0 billion in Cities

Source: United Nations Department of Economic and Social Affairs Population Division:
World Urbanization Prospects, The 2011 Revision
Basis of Research

Source: David Dodman, Blaming Cities for Climate Change? An Analysis of Urban Greenhouse Gas Emissions Inventories, 2009
Basis of Research

Transport-related energy consumption
Gigajoules per capita per year

Urban density and transport-related energy consumption

Basis of Research
Basis of Research

Steel: Melting Iron
Concrete: Cement Production
Wood: Kiln Drying
Basis of Research

- Renewable Resource
- Global Warming Potential
- Air & Water Quality
- Erosion and Soil Quality
- Biodiversity
Basis of Research
Basis of Research
Basis of Research
Initial Research Project
Overview
Research Project Overview
Research Project Overview
Research Project Overview

“Analysis and design of framed tube structures for tall concrete buildings”
The Structural Engineer, March 1973
Research Project Overview
Design Process

What makes a ‘successful’ building design?

- Marketable
- Serviceable
- Economical
- Sustainable
Successful Design

Marketable

Serviceable

Economical

Sustainable
Proposed System

- Solid 8" Thick Timber Floor Panels
- Built Up Timber Columns
- Reinforced Concrete Spandrel Beam
- Reinforced Concrete Wall Joint
- Timber Framing Within Core
- Reinforced Concrete Link Beams
- Solid Timber Shear Walls

Typical Floor Structure
System Design
Marketable

24ft Average

27-29 ft
Marketable
Marketable
System Marketability

- 26’-3”
- Need ~13.5” th. panel
- Too much material, not economical
Floor Structure

We must reduce amount of materials used in the floors, what choices do we have?

- Reduce the span?
- Add interior columns / walls?
- Use beams?
- Boundary conditions?
Floor Structure
Floor Structure
Floor Structure
Floor Structure

**Simple Support**
- Concrete: 14"
- Steel: W14x22 @ 10’ O.C.

**Fixed Support**
- Concrete: 8"
- Steel: W14x22 @ 10’ O.C., Not Practical

Figure A.4: Floor Systems and Beam Deflection Diagrams
Floor Structure

We must reduce amount of materials used in the floors, what choices do we have?

- Reduce the span?
- Add interior columns / walls?
- Use beams?
- Boundary conditions
Floor Connections

Typical Framing Plan

Typical Floor Section

Column to Slab Connection

Tension Rebar
Floor Connections
Floor Analysis

<table>
<thead>
<tr>
<th>Floor System</th>
<th>Simple Support Concrete</th>
<th>Continuous Support Concrete (Fixed)</th>
<th>Simple Support Timber</th>
<th>Continuous Support Timber (Fixed)</th>
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</thead>
<tbody>
<tr>
<td>Strength</td>
<td>0.83</td>
<td>1.00</td>
<td>Service 0.29</td>
<td>Fire 0.53</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.87</td>
<td>Service 0.35</td>
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</tr>
<tr>
<td>Deflection</td>
<td>1.00</td>
<td>0.75</td>
<td>Fire 1.00</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>0.97</td>
<td></td>
</tr>
<tr>
<td>Vibration</td>
<td>Vel. 0.59</td>
<td>Vel. 0.80</td>
<td>Vel. 1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Accel. 0.21</td>
<td>Accel. 0.27</td>
<td>Accel. 0.50</td>
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<tr>
<td>System</td>
<td>13.75&quot;</td>
<td>8.1&quot;</td>
<td>10.83&quot;</td>
<td>6.88&quot;</td>
</tr>
<tr>
<td>Summary</td>
<td>$A_1 = 0.0037$</td>
<td>$A_2 = 0.0037$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Floor Connections
Floor Connections
Floor Connections
Timber / Concrete Material Properties

Select Structural SPF

5,000 psi Concrete
Torsional Behavior

(a) Thin-walled tube

(b) Area enclosed by shear flow path

Fig. R11.6.3.6(a)—Space truss analogy
Floor to Floor Compression

Trump Tower Material Schedule

<table>
<thead>
<tr>
<th>ZONE</th>
<th>MINIMUM CONCRETE COMpressive STRENGTH (PSI)</th>
<th>ASSUMED AVERAGE ELASTIC MODULUS (KSI)</th>
<th>ASSUMED DENSITY (PCF)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25-DAY 56-DAY 90-DAY</td>
<td>28-DAY 56-DAY 90-DAY</td>
<td>28-DAY 56-DAY 90-DAY</td>
</tr>
<tr>
<td>LEVEL 1-4-29 (TYP)</td>
<td>- - 12,000</td>
<td>- -</td>
<td>6,000 155</td>
</tr>
<tr>
<td>LEVEL 29-51 (TYP)</td>
<td>- - 12,000</td>
<td>- -</td>
<td>6,000 155</td>
</tr>
</tbody>
</table>
Floor to Floor Compression
Concrete Column/Floor Joints

Trump Tower Material Schedule

<table>
<thead>
<tr>
<th>ZONE</th>
<th>MINIMUM CONCRETE COMPRESSIVE STRENGTH (PSI)</th>
<th>ASSUMED AVERAGE ELASTIC MODULUS (KSI)</th>
<th>ASSUMED DENSITY (PSF)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>28-DAY</td>
<td>56-DAY</td>
<td>90-DAY</td>
</tr>
<tr>
<td>LEVEL L4-28 (TYP)</td>
<td>-</td>
<td>-</td>
<td>12,000</td>
</tr>
<tr>
<td>LEVEL 29-51 (TYP)</td>
<td>-</td>
<td>-</td>
<td>12,000</td>
</tr>
</tbody>
</table>

Column is 2.2x stronger than typical floor
Timber Column/Floor Joints

425 psi Allowable

1400 psi Allowable

Column is 3.3x stronger than typical floor
Timber Column/Floor Joints

Beam applies tension perpendicular to column grain

425 psi
Allowable

1400 psi
Allowable
Timber Column / Concrete Floor Joint

C = 1,400 psi

C = 2,500 psi (MIN)

The floor is 1.8x stronger than the column!
Proposed System

- Built up timber columns
- Solid 8" thick timber floor panels
- Reinforced concrete spandrel beam
- Reinforced concrete wall joint
- Timber framing within core
- Reinforced concrete link beams
- Solid timber shear walls

Typical floor structure
Proposed System

Benchmark Building, Take-Off Quantities:
Sub & Superstructure:
Concrete: 0.98 cu.ft/sf
Reinforcement: 5.9 psf
Foundations:
Concrete: 0.14 cu.ft/sf
Reinforcement: 0.1 psf

Prototypical Building, Estimated Quantities:
Sub & Superstructure:
Timber: 0.80 cu.ft/sf
Concrete: 0.25 cu.ft/sf
Reinforcement: 1.7 psf
Structural Steel: 0.3 psf
Foundations:
Concrete: 0.09 cu.ft/sf
Reinforcement: 0.1 psf
Proposed System

Benchmark Building, Take-Off Quantities:
- Sub & Superstructure:
  - Concrete: 0.98 cu.ft/sf
  - Reinforcement: 5.9 psf
- Foundations:
  - Concrete: 0.14 cu.ft/sf
  - Reinforcement: 0.1 psf

Prototypical Building, Estimated Quantities:
- Sub & Superstructure:
  - Timber: 0.80 cu.ft/sf
  - Concrete: 0.25 cu.ft/sf
  - Reinforcement: 1.7 psf
  - Structural Steel: 0.3 psf
- Foundations:
  - Concrete: 0.09 cu.ft/sf
  - Reinforcement: 0.1 psf

Total Lumber:
- = 12,000 yd$^3$
- = 3.9 million board-ft
- = 1,700 miles of 2x4
Design Process

What makes a ‘successful’ building design?

- Marketable
- Serviceable
  - Tall Buildings
  - Timber Buildings
- Economical
- Sustainable
Serviceability in Tall Buildings
Proposed System
Lateral Load Resistance

Lateral Load Deformation

Link Beam Deformation
Lateral Load Resistance

Concrete
Vallow = 100 kips

Steel
Vallow > 300 kips

Timber
Vallow = 40 kips

Figure A.3: Maximum Available Link Beam Shear
Managing Vertical Loads

Lateral Load Deformation

Overturning Diagram

Lateral Load Tributary Area
Compression Strength

<table>
<thead>
<tr>
<th>Material</th>
<th>Reinforced Concrete</th>
<th>Steel</th>
<th>Timber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross Section</td>
<td>20&quot;x20&quot;</td>
<td>W14x99</td>
<td>24&quot;x24&quot;</td>
</tr>
<tr>
<td>Concrete $f_c$</td>
<td>6,000 psi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel $f_y$</td>
<td>50 ksi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Timber $F_c$</td>
<td>1,150 psi</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Uplift Resistance
Proposed System

By Volume: 80% Timber, 20% Concrete
By Weight: 45% Timber, 55% Concrete

Typical Floor Structure
Design Process

What makes a ‘successful’ building design?

- Marketable
- Serviceable
  - Tall Buildings
  - Timber Buildings
- Economical
- Sustainable
Serviceability – Fire Resistance
Serviceability – Fire Resistance

- Solid 8” Thick Timber Floor Panels
- Built Up Timber Columns
- Reinforced Concrete Spandrel Beam
- Reinforced Concrete Wall Joint
- Timber Framing Within Core
- Reinforced Concrete Link Beams
- Solid Timber Shear Walls

Typical Floor Structure
Serviceability – System Integration
Serviceability – Acoustics

**Estimated Acoustic Performance**

**DeWitt-Chestnut**

- STC = 57
- IIC ≥ 65

**Estimated Acoustic Performance**

**Rental Apartments**

- STC ≥ 55
- IIC ≥ 60
Serviceability – Moisture / Durability

ESTIMATED ACOUSTIC PERFORMANCE
RENTAL APARTMENTS

STC ≥ 55
IIC ≥ 60

TYPICAL WALL JOINT

TYPICAL SPANDREL JOINT
Serviceability – Lower Levels
Design Process

What makes a ‘successful’ building design?

-> Marketable

-> Serviceable

-> Economical

-> Sustainable
Sustainability

Figure 6.1: Embodied Carbon Footprint Comparison, Standard Materials
Effective Use of Timber

Sub & Superstructure:
- Concrete: 0.98 cu.ft/sf
- Reinforcement: 5.9 psf

Foundations:
- Concrete: 0.14 cu.ft/sf
- Reinforcement: 0.1 psf

Total Mat'l = 1.12 cuft/sf
C0₂ Footprint = 75lb/sf

Sub & Superstructure:
- Timber: 0.80 cu.ft/sf
- Concrete: 0.25 cu.ft/sf
- Reinforcement: 1.7 psf
- Structural Steel: 0.3 psf

Foundations:
- Concrete: 0.09 cu.ft/sf
- Reinforcement: 0.1 psf

Total Mat'l = 1.14 cuft/sf
C0₂ Footprint = 30lb/sf

Sub & Superstructure:
- Timber: 1.22 cu.ft/sf
- Concrete: 0.07 cu.ft/sf
- Reinforcement: 0.4 psf
- Structural Steel: 0.7 psf

Foundations:
- Concrete: 0.08 cu.ft/sf
- Reinforcement: 0.1 psf

Total Mat'l = 1.30 cuft/sf
C0₂ Footprint = 20lb/sf
Effective Use of Timber

North America produces approximately 20 billion board-ft of lumber each year?

How can this material be used most effectively?
Effective Use of Timber

Using SOM proposed composite system, 20b bd-ft = 2,050,000,000 SF of high-rise

Using SOM proposed all-timber system, 20b bd-ft = 1,350,000,000 SF of high-rise
Effective Use of Timber

Using SOM proposed composite system, 20b bd-ft = 2,050,000,000 SF of high-rise

Using SOM all-timber & concrete systems, 20b bd-ft = 1,350,000,000 SF of timber high-rise + 700,000,000 SF of R/C high-rise
Effective Use of Timber

Using SOM proposed composite system, 20b bd-ft = 2,050,000,000 SF of high-rise

Average Material Usage = 1.12 cuft/sft
Average Carbon Footprint = 30lb/sf

Using SOM all-timber & concrete systems, 20b bd-ft = 1,350,000,000 SF of timber high-rise + 700,000,000 SF of R/C high-rise

Average Material Usage = 1.25 cuft/sft
Average Carbon Footprint = 40lb/sf
Design Process

What makes a ‘successful’ building design?

- Marketable
- Serviceable
- Economical
- Sustainable
Concrete Jointed Timber Frame
Moving Forward:
System Report #1
Section 7: Recommendations

7.1 General
The proposed structural system, as developed using the finite element program, is examined in detail to determine the effects of variables. These variables include the joint geometry, the interaction of the system with the building's exterior, the methods of strengthening and the loading conditions. The following are the recommendations for additional work.

7.2 Research
Specific recommendations are presented in Section 7.1.

7.3 Technical Studies
The following technical studies are recommended:

- Additional numerical models of the structural system should be developed to further investigate the effects of different variables.
- Experimental tests on small-scale models should be conducted to verify the predictions of the numerical models.
- Detailed analyses of the interaction between the structural system and the building's exterior should be performed.
- The effects of strengthening on the performance of the structural system should be investigated.

7.4 Cost Estimation
Cost estimates are required for the proposed structural system. These estimates should include the cost of the structural system itself, as well as the cost of the necessary additional work. The cost estimates should be compared to the cost benefits anticipated from the implementation of the proposed system.

7.5 Conclusion
The proposed structural system is recommended for further study and implementation. The recommended work is expected to provide valuable insight into the behavior of similar structural systems and to contribute to the development of more effective design procedures.
Collaboration

- Precast spandrel supported on columns below
- Joint reinforced, set with walls
- Steel element to secure panel & column above

Primary structure construction proceeds up the building, stages 1-6

Secondary core elements constructed lower in building

Enclosure and fit-out

Stage 2

Stage 8
Collaboration

A1.1: Contractor Review Summary

The following design considerations were highlighted in a review of the original system by contractors knowledgeable with high-rise construction:

- The system should use ‘column trees’ to minimize pick counts. The precast beam splices shown have been designed to achieve this.
- Field assembly of precast beam and timber column trees adds cost. Beams and columns within the tree should be connected off site. Column joint shown in Figure 2-7 indicates a shop connection. Columns would be spliced approximately 4'-0" above the floor, similar to columns in a structural steel building.
- The acoustic concrete topping adds cost. Make this topping structural and composite to offset the cost of the topping with timber plank thickness savings.
- The ceiling finishes add significant cost. The system as shown uses a thin visual grade which is structural and exposed, offsetting this cost.
- Routing of electrical conduit within the floor thickness is not as simple as a cast-in-place concrete slab. The revised system could route conduit within the top ply of the mass-timber floor and partially within the concrete topping without compromising the structural performance.
- Fireproofing of connections if required will add cost and needs to be considered.
- The floor-to-floor height had to be taller for the original system. The composite topping and exposed visual grade approach reduces the ceiling sandwich dimension. This will reduce costs due to floor-to-floor height differences.
- The composite-timber system will save on foundations due to less total gravity load. The system as shown in this report is approximately 5% lighter due to weight savings in the concrete joints.
“Big Picture” Sustainability

**Columns:**
- Material: 5-10%
- Testing: Some
- Use: Timber
- Building Only

**Floor Framing:**
- Material: 65-75%
- Testing: Some
- Use: Timber or Hybrid Building

**Shear Walls:**
- Material: 15-25%
- Testing: Extensive
- Use: Timber Building Only
System Report #1

TIMBER TOWER RESEARCH PROJECT

System Report #1
Gravity Framing Development of
Concrete Jointed Timber Frame System

May 30th, 2014

Figure 2-11a: Column & Wall Bending Behavior

Figure 2-11b: Column & Wall Bending Behavior

Figure 2-12: Construction Sequencing Efforts

Figure 2-12: Construction Sequencing Efforts

Figure 5-2: (a) Fundamental Mode Shape, T = 0.117sec and f = 7.32Hz; (b) Plan View of First Three Modes

System Report #1
Gravity Framing Development of CTF System

System Report #1
Gravity Framing Development of CTF System
System Report #1
Second Generation System
Second Generation System

Composite structural concrete topping slab, reduces overall th.
Second Generation System

Composite structural concrete topping slab, reduces overall th.

Visual grade of wood on underside to eliminate finishes
Second Generation System

Composite structural concrete topping slab, reduces overall th.

Visual grade of wood on underside to eliminate finishes

Route conduit at interface of timber and topping
Second Generation System

Bars in topping slab provide moment connection to concrete boundary structure
Researcher Collaboration
Moving Forward:
Project Opportunities
Opportunities

Reduced massing on elevation
Roof terrace
Opportunities
Opportunities
Opportunities
Conclusions
Conclusions
Conclusions
Conclusions

Photo Credit: S.H. Knox & Company

SOM | Nick Merrick © Hedrich Blessing

~100 Years
Conclusions
42-Story Dewitt-Chestnut Apartments Re-imagined: The SOM Timber Tower Research Project

Thank You
42-Story Dewitt-Chestnut Apartments Re-imagined: The SOM Timber Tower Research Project

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